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The Cenomanian and Turonian (mid-Cretaceous) ammonite biostratigraphy of north-eastern Nigeria

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Synopsis. The Cenomanian–Turonian ammonite biostratigraphy of the Pindiga Formation and its age equivalents was investigated at a number of localities in north-eastern Nigeria. Five biozones were found to be recognizable in the main limestone-bearing sequences of the region as a whole: a Zone of *Nigericeras gadeni* (Chudeau) at the base, a Zone of *Vascoceras cauvini* Chudeau, a Zone of *Vascoceras proprium* (Reyment), a Zone of *Pseudotissotia nigeriensis* (Woods) and a Zone of *Wrightoceras wallsi* Reyment above. The Gadeni and Cauvini Zones are Late Cenomanian in age while the Nigeriensis and Wallsi Zones are Early Turonian. The Cenomanian–Turonian boundary lies within or at the top of the Proprium Zone. The Wallsi Zone at Dukul is overlain by a condensed horizon containing *Fagesia* sp., *Neoptychites cephalotus* (Courtiller), *Wrightoceras munieri* (Pervinquière) and *Hoplitoides ingens* (von Koenen), ammonites ranging from Lower to Middle Turonian. The youngest Turonian zone recognizable is that of *Coilopoceras discoideum* Barber. A broadly similar ammonite succession occurs in the Algerian Sahara, while correlation of these Nigerian zones with those in Israel is good, especially in the Upper Cenomanian. Local subsidence history had a profound effect on the age, thickness and lithological character of the ammonite-bearing sequences in north-eastern Nigeria; all these factors vary significantly.

INTRODUCTION

The Cenomanian–Turonian limestones of north-eastern Nigeria have long been noted for their prolific vascoceratid-dominated ammonite faunas. Elements were first described by Woods (1911), but following the accounts of Reyment (1954, 1954*a*, 1955) and Barber (1957, 1960) the full wealth of these assemblages became evident. This area has subsequently assumed major importance in mid-Cretaceous Tethyan biostratigraphy. The ammonite-bearing beds outcrop widely but in its details the geology of the region is rather complex, a fact reflected by the multiplicity of lithostratigraphical and palaeogeographical terms applied to it. Cretaceous sedimentation in north-eastern Nigeria was, for its greater part, strongly influenced by a number of important strike-slip faults trending NE–SW (Benkhelil 1982, Benkhelil & Robineau 1983, Popoff *et al.* 1983, Maurin *et al.* 1986; Fig. 1). Two major sedimentary basins are present, the Chad Basin to the north and the Lau Basin (Benue Basin of Carter *et al.* (1963), Lamurde Basin of Ojo & Pinna (1982)), comprising the distal part of the Benue Trough, to the south. The area between, termed the 'Zambuk Ridge' by Carter *et al.* (1963), is characterized by strong faulting which resulted in the development of several differentially subsiding basins (Ojo & Pinna 1982, Maurin *et al.* 1986). Following the first systematic geological mapping of the region, Carter *et al.* (1963) referred the Cenomanian–Turonian limestone-shale sequence in the western part of the Chad Basin to the Gongila Formation, that in the Lau Basin to the Dukul Formation and that in the remaining area to the Pindiga Formation. These marine formations overlie a transitional sandstone-shale sequence (the Yolde Formation) over most of north-eastern Nigeria. The earliest sediments are a thick but varied fluviatile and

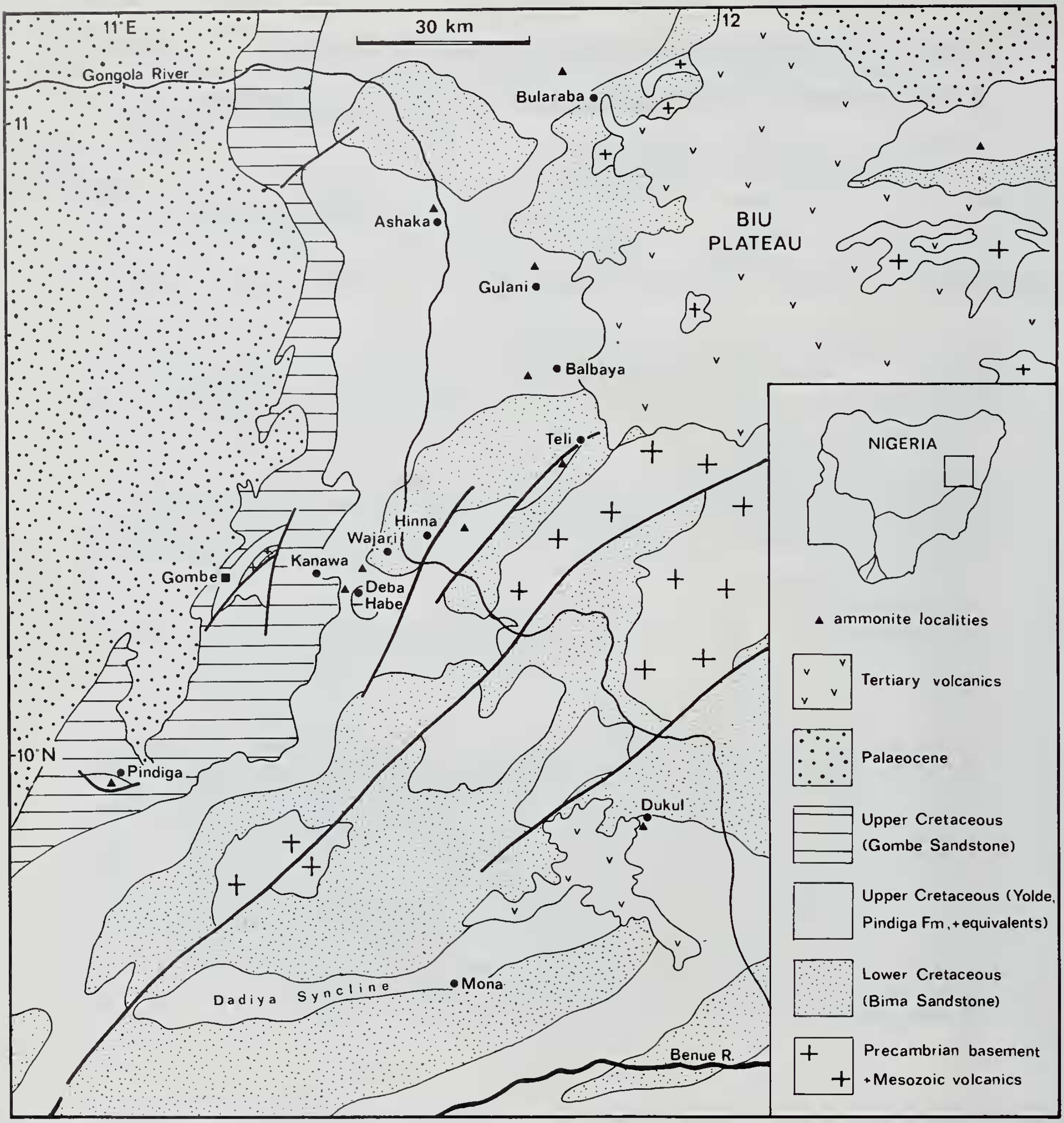


Fig. 1 Simplified geological map of part of north-eastern Nigeria showing ammonite localities mentioned in the text.

lacustrine succession, the Bima Sandstone of Aptian to Albian age (Allix *et al.* 1981, Doyle *et al.* 1982) which underlies the entire area.

Woods (1911) established the presence of Turonian deposits in north-eastern Nigeria but Reyment (1954) proposed the first subdivision of this stage in Nigeria, regarding the vascoceratid-dominated faunas as characteristic of his 'Oldest Beds' (of the Turonian). These beds he subsequently referred to as the 'Zone of *Pachyvascoceras costatum* Reyment' and, later, as the 'Zone of *Pseudotissotia* (*Wrightoceras*) *wallsi* Reyment' (Reyment 1956, 1965). Barber (1957), however, proposed three zones for this sequence in north-eastern Nigeria: a Zone of *Vascoceras bulbosum* (Reyment) below, a Zone of *Paravascoceras costatum* (Reyment) and a Zone of *Pseudotissotia* (*Bauchioceras*) *nigeriensis* above. All were assigned to the Lower Turonian, though Barber noted the Cenomanian affinities of elements of his Bulbosum Zone fauna. Wozny & Kogbe (1983) later proposed a 'Zone of *Gombeoceras gongilense* Reyment' between Barber's Costatum and Nigeriensis Zones. These three zones they referred to the Lower Turonian, regarding Barber's Bulbosum Zone as Upper Cenomanian. Most recently, Popoff *et al.* (1986) reinvestigated the Gongila Formation at Ashaka Quarry and the Pindiga Formation at its streamside type locality (see Fig. 1). They divided the ammonite-bearing levels into seven zones, as follows:

BARBER (1957)	WOZNY & KOGBE (1983)	POPOFF et al. (1986)	PRESENT WORK
Pseudotissotia (Bauchioceras) nigeriensis	Pseudotissotia (Bauchioceras) nigeriensis	Choffaticeras barjonae/ Fagesia n. sp.	Wrightoceras wallsi
		Wrightoceras wallsi	
	Gombeoceras gongilense	Pseudotissotia nigeriensis	Pseudotissotia nigeriensis
Paravascoceras costatum	Paravascoceras costatum	Paravascoceras costatum	Vascoceras proprium
Vascoceras bulbosum	Vascoceras bulbosum	Vascoceras bulbosum	
		Vascoceras tavense	Vascoceras cauvini
		Nigericeras gadeni	Nigericeras gadeni

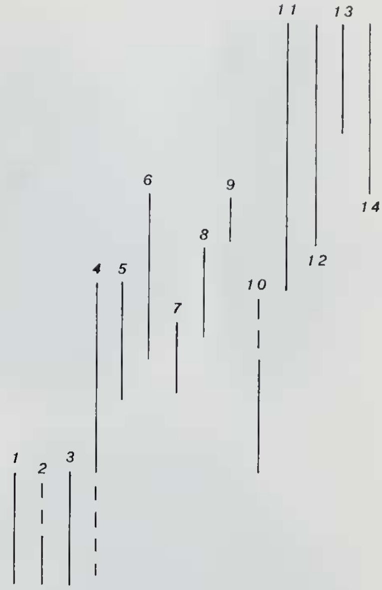


Fig. 2 Present and previous proposals for a biostratigraphical subdivision of the Upper Cenomanian and Lower Turonian in north-eastern Nigeria based on ammonites. The stratigraphical ranges of selected forms are shown at right: 1, *Metengonoceras dumbli*. 2, *Metoicoceras geslinianum*. 3, *Nigericeras gadeni*. 4, *Vascoceras cauvini*. 5, *V. nigeriense*. 6, *V. proprium*. 7, *V.* sp. juv. 8, '*Paramammites*' sp. 9, *Pseudaspidoceras* cf. *flexuosum*. 10, *P.* cf. *pseudonodosoides*. 11, *Thomasites gongilensis*. 12, *Pseudotissotia nigeriensis*. 13, *Wrightoceras wallsi*. 14, *Eotissotia simplex*.

7. Zone of *Choffaticeras barjonae* (Choffat)/*Fagesia* n. sp. (youngest)
6. Zone of *Wrightoceras wallsi*
5. Zone of *Pseudotissotia nigeriensis*
4. Zone of *Paravascoceras costatum*
3. Zone of *Vascoceras bulbosum*
2. Zone of *Vascoceras tavense* Faraud
1. Zone of *Nigericeras gadeni* (Chudeau) (oldest).

Zones 1–3 were dated Late Cenomanian, the Costatum Zone Early Turonian and zones 5–7 Middle Turonian.

There has, therefore, been a divergence of opinion regarding the biostratigraphical subdivision and precise ages of these beds. One of the main problems in dealing with vascoceratid faunas is ascertaining the limits of individual species which are frequently represented by a large array of morphotypes (see, for example, Schöbel 1975, Renz 1982, Hirano 1983, Berthou *et al.* 1985, Kennedy *et al.* 1987). The taxonomic approaches adopted by previous authors have strongly influenced their biostratigraphical and palaeobiogeographical interpretations of the Nigerian faunas. The purpose of this contribution is not to attempt a complete taxonomic revision of these ammonites but rather to propose a biostratigraphy effective in correlation both within and outside north-eastern Nigeria. Inevitably, however, certain taxonomic remarks are necessary especially in regard to those species that have been selected as zonal indices.

PROPOSED BIOZONATION

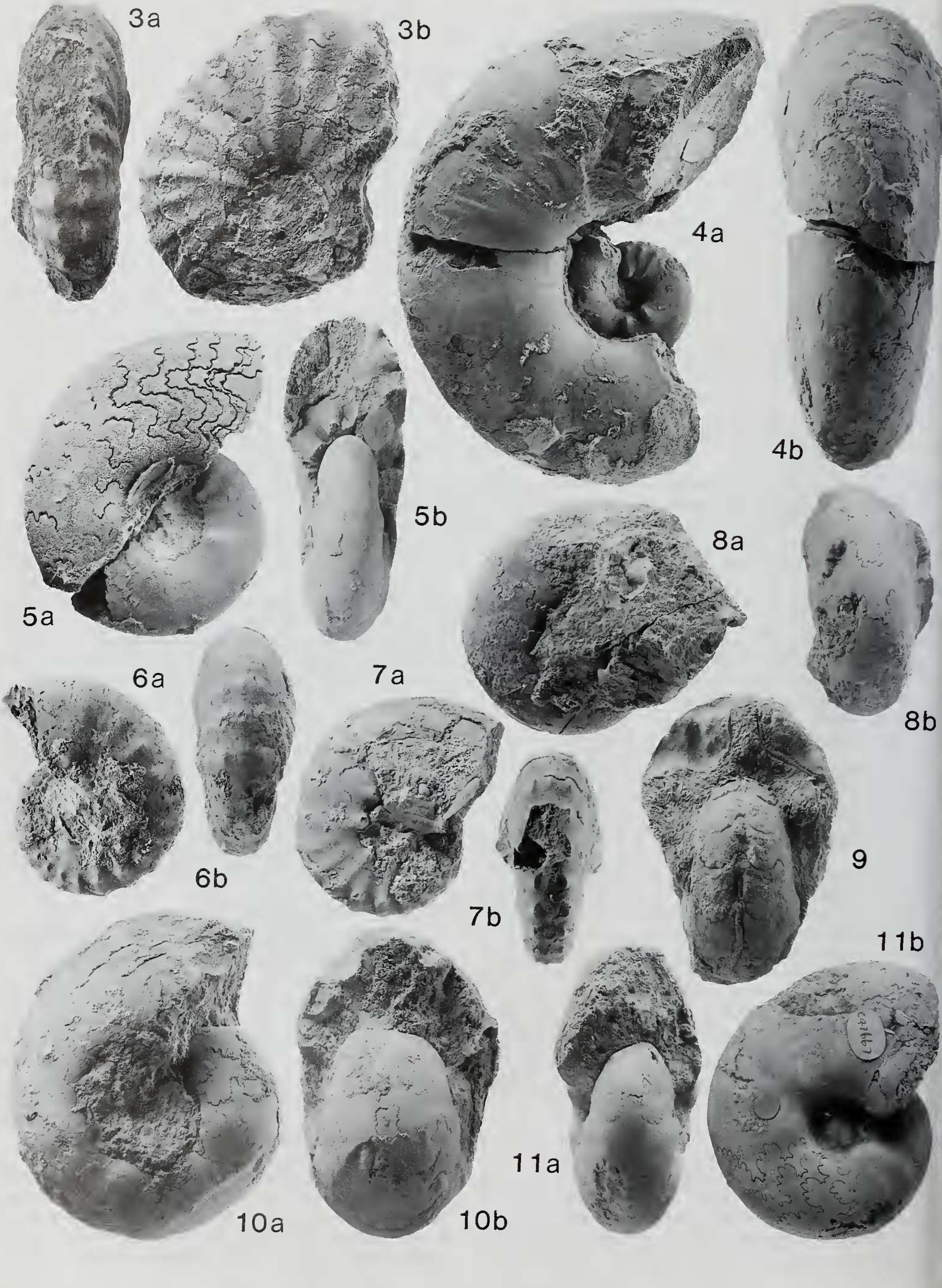
The following ammonite biozones are proposed for the main part of the Late Cenomanian and Early Turonian limestone-bearing sequences in north-eastern Nigeria:

5. Zone of *Wrightoceras wallsi* (youngest)
4. Zone of *Pseudotissotia nigeriensis*
3. Zone of *Vascoceras proprium* (Reyment)
2. Zone of *Vascoceras cauvini* Chudeau
1. Zone of *Nigericeras gadeni* (oldest).

This scheme has been found to be applicable over the region as a whole. Zones 1–4 are interval zones, defined at their bases by the appearances of the index species. Zone 5 is a range zone based on the local occurrence of *W. wallsi*. The relationship of these zones to previously proposed schemes is shown in Fig. 2. As discussed below, the Wallsi Zone is locally overlain by a fauna containing, amongst others, *Hoplitoides*. At Mona and Bularaba (Fig. 1) still younger Turonian beds contain *Coilopoceras discoideum* Barber.

The *Nigericeras gadeni* Zone

A Zone of *Nigericeras gadeni* was first proposed by Popoff *et al.* (1986) for the earliest ammonite-bearing beds in north-eastern Nigeria. Although ammonites are generally scarce in this zone, *N. gadeni* occurs in some numbers and has a wide geographical distribution in the region. In this study it has not been found outside the Gadeni Zone, but Popoff *et al.* (1986: 348) reported it from Ashaka Quarry as high as beds included here in the *Vascoceras proprium* Zone. Faunas characteristic of the Gadeni Zone can be recognized in the lowest limestone bed at Pindiga (unit 1 of Barber 1957: table 3; unit 3 of Popoff *et al.* 1986: 354); at Ashaka Quarry (units 2 and 3 of Popoff *et al.* 1986: 347; the former, contrary to their statement, being exposed in a drainage cut in the eastern part of the quarry); in the lowest limestone bed exposed at Deba Habe; in the region between Kanawa and Hinna; at Teli; and to the north-east of the Biu basalt plateau (see Fig. 1). At the last two localities the Gadeni Zone is the only ammonite biozone present.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Material of *N. gadeni* from north-east Nigeria is variable as regards strength and persistence of the juvenile ornamentation (Figs 4–7). Numerous specimens resemble in particular *N. lamberti* Schneegans (1943: 121; pl. 6, figs 1–5, 7). In agreement with Schöbel (1975) and Wright & Kennedy (1981), *N. lamberti*, *N. gignouxi* Schneegans (1943: 119; pl. 5, figs 10–15) and *N. jacqueti* Schneegans (1943: 125; pl. 6, fig. 8; pl. 7, fig. 1) are here regarded as synonyms of *N. gadeni* (Chudeau 1909: 71; pl. 3, fig. 6), making up a series varying mainly in the ornamental details mentioned above. The Gadeni Zone has also yielded *Metengonoceras dumbli* (Cragin) at Pindiga and Deba Habe. East of Kanawa a single specimen of *Metoicoceras geslinianum* (d'Orbigny) (Fig. 3) was found in scree which otherwise produced only rare *Metengonoceras dumbli*, more frequent *Nigericeras gadeni* and a poorly preserved fragment of *Vascoceras*. A fragment of a compressed *Vascoceras*, perhaps referrable to *V. cauvini*, was also found in the lowermost limestone bed at Pindiga. Two further, rather better preserved, immature specimens of *Vascoceras* (Figs 9, 10) were collected from the same bed. One of these (Fig. 10) shows broad, clavate umbilical tubercles similar to those discernible in the holotype of *V. bulbosum* (Reyment 1954*a*: pl. 4, figs 2a, b). The Pindiga individual is more inflated but is linked to the latter specimen by an ammonite referred to *V. bulbosum* by Barber (1957: pl. 6, fig. 8; Fig. 11 here). The Pindiga material mentioned above may be conspecific with *V. bulbosum* which itself is a possible synonym of *V. cauvini* Chudeau (see below). If *V. cauvini* is confirmed at this stratigraphical level in Nigeria, the Cauvini Zone can be extended downwards to include those beds here referred to as the Gadeni Zone, with the latter possibly being retained as a subzone. Popoff *et al.* (1986) reported *Eotissotia* Barber from the Gadeni Zone at Pindiga. This genus is otherwise found only at much higher stratigraphical levels in the Nigeriensis and Wallsi Zones. Finally, a fragment of a depressed ammonite with an acanthoceratid ornament (British Museum (Natural History) C.91294), possibly referrable to *Euomphaloceras*, was found in the Gadeni Zone at Pindiga.

The *Vascoceras cauvini* Zone

The base of this zone is marked by the appearance of *Vascoceras cauvini*, which can at present be drawn in the middle of unit 3 of Barber (1957: table 3), that is unit 4 of Popoff *et al.* (1986: 354), at Pindiga, and at the base of unit 4 of Popoff *et al.* (1986: 348) at Ashaka. It encompasses the greater part of the '*Vascoceras bulbosum* Zone' of Barber (1957) and the '*Vascoceras tavense* Zone' and lower part of the '*Vascoceras bulbosum* Zone' of Popoff *et al.* (1986) (see Fig. 2).

The Cauvini Zone is characterized by the common occurrence of moderately involute, compressed *Vascoceras*, generally smooth or nearly so in the juvenile whorls but sometimes with broad umbilical bullae. Such forms were referred by Barber (1957) to *V. bulbosum* (see Barber 1957: pl. 6, figs 6, 8) and *V. depressum* Barber (1957: 19; pl. 6, fig. 5). Only immature specimens have been found at Pindiga (Figs 8, 15). At other localities, notably Ashaka Quarry, the later growth stages are well represented and show the characteristic ventral ribbing of *V. cauvini* Chudeau (1909: 68; pls 1–2; pl. 3, figs 1, 2, 4) to which these specimens are here referred. A series of specimens at different growth stages is shown in Figs 12–14. *V. bulbosum* itself is based on a rather more inflated specimen than these (C.47295; see Reyment 1954*a*: pl. 4, figs 2a, b) showing broad, clavate umbilical ornamentation. It is, however, closely matched in whorl proportions by a specimen from Damergou included in *V. cauvini* by Chudeau (1909: pl. 3, figs 4a, b). This individual was refigured by Schneegans (1943: pl. 4, fig. 1) as *Paravascoceras nigeriensis* (Woods), apparently because of its early loss of umbilical tuberculation. Both Reyment (1954*a*: 256) and Barber (1957: 15) also tentatively referred it to this species. Contrary to the impression given by Woods (1911), however, rapid loss of ornamentation is by no means a characteristic feature of *Vascoceras nigeriense*. Certain specimens retain umbilical tubercles, often becoming bullate, to diameters of 70 mm or more (Fig. 25). It is possible that Chudeau's individual mentioned above is a true *V. cauvini* of which *V. bulbosum* may be a synonym. A list of further possible synonyms has been given by Schöbel (1975).

At Pindiga the uppermost part of the Cauvini Zone and the lowermost part of the overlying Proprium Zone consist of two thin calcareous beds separated by 50 cm of shales with gypsum (unit 5 of Barber 1957: table 3). These calcareous beds contain a stratigraphically important but taxonomically problematical assemblage of juvenile *Vascoceras* (Figs 17–18, 20). At Deba Habe a comparable association (Figs 16, 21) again occurs in an equivalent stratigraphical position. Barber (1957: 27) noted the similarity of some of these forms to *V. nigeriense* but, uncertain of their precise affinities, left them in open nomenclature as '*Vascoceras* sp. juv.' These individuals are consistently rather evolute and ventrally are either smooth or with only broad, low ribs. Their umbilical ornament, however, is highly variable. In some (Fig. 20) there are comparatively small, rounded umbilical tubercles. More commonly prominent, highly bullate umbilical tubercles are present, giving off single or paired indistinct ribs which fade over the venter (Figs 17, 21). This range of ornament is reminiscent of that in *Vascoceras diartianum* (d'Orbigny) (see Kennedy & Juignet 1977) and in particular of an assemblage from the Upper Cenomanian of southern Germany described by Förster *et al.* (1983: 133; pl. 3, figs 1–5). Others still show large, frequently paired, umbilical bullae (Fig. 18). Such massive tuberculation recalls that in *V. silvanense* Choffat (1898: 57; pl. 8, fig. 5; pl. 21, fig. 9), a form based on a juvenile of uncertain affinity (Berthou *et al.* 1985: 68). Although, within the Nigerian faunas, *V. nigeriense* is closest in whorl proportions to these juveniles, their variability precludes assignment to this species with confidence, if indeed they are all conspecific. It should also be noted that

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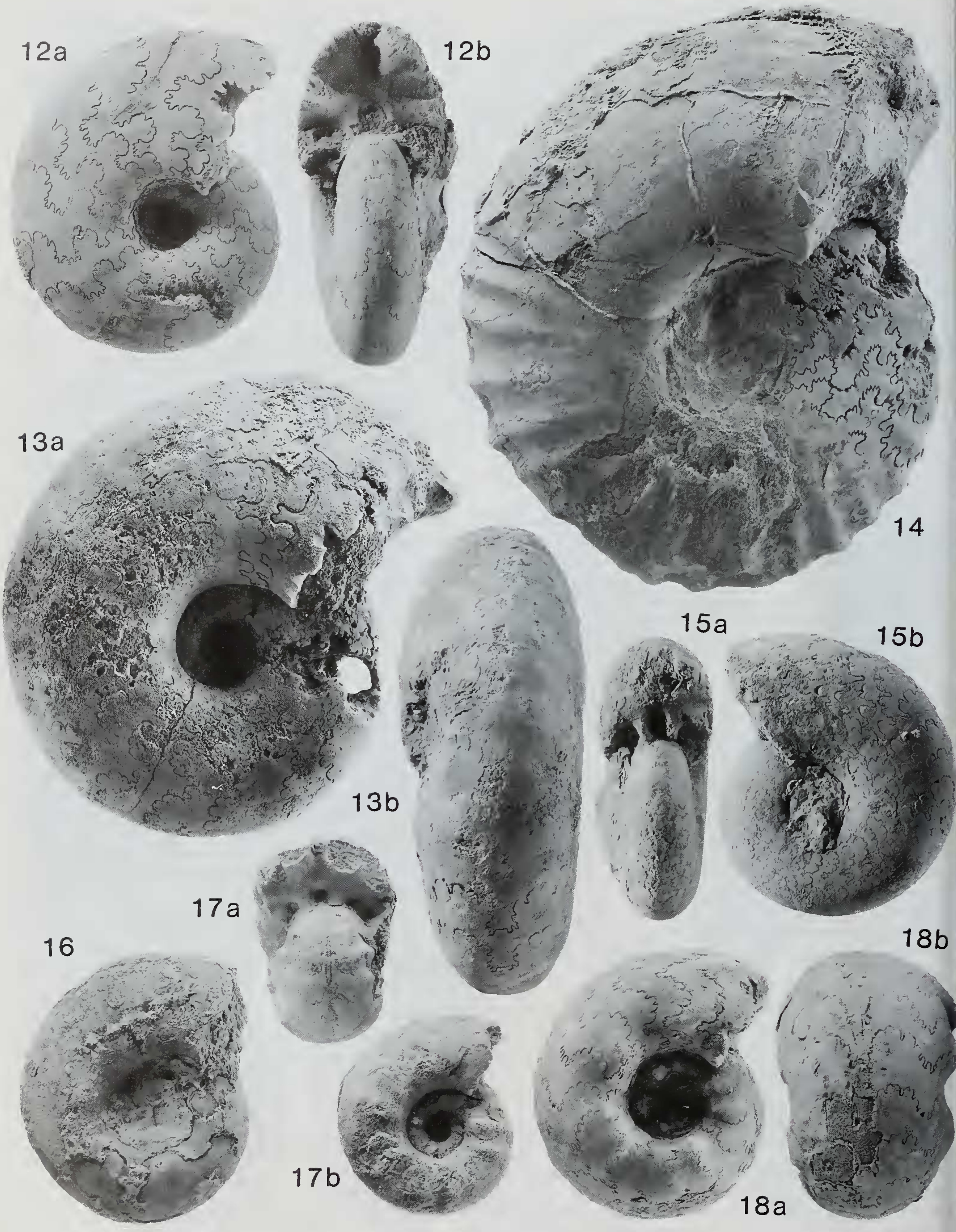
Figs 3a, b *Metoicoceras geslinianum* (d'Orbigny). Pindiga Formation (Gadeni Zone), between Kanawa and Wajari. C.91205, × 1.
Figs 4–7 *Nigericeras gadeni* (Chudeau). Pindiga Formation (Gadeni Zone). Figs 4a, b, C.91209, × 1. North-east of Biu plateau. Figs 5a, b, C.91212, × 1. Teli. Figs 6a, b, C.91215, × 1. Between Kanawa and Wajari. Figs 7a, b, C.91216, × 1. Between Kanawa and Wajari.
Figs 8a, b *Vascoceras cauvini* Chudeau. Pindiga Formation (Cauvini Zone), Pindiga. C.91285, × 1.
Figs 9, 10 *Vascoceras* sp. Pindiga Formation (Gadeni Zone), Pindiga. Fig. 9, C.91225, × 1. Figs 10a, b, C.91224, × 1.
Figs 11a, b *Vascoceras bulbosum* (Reyment). Pindiga Formation, Pindiga. C.47667, × 1 (see also Barber 1957: pl. 6, fig. 8).
All specimens are housed in the British Museum (Natural History), London.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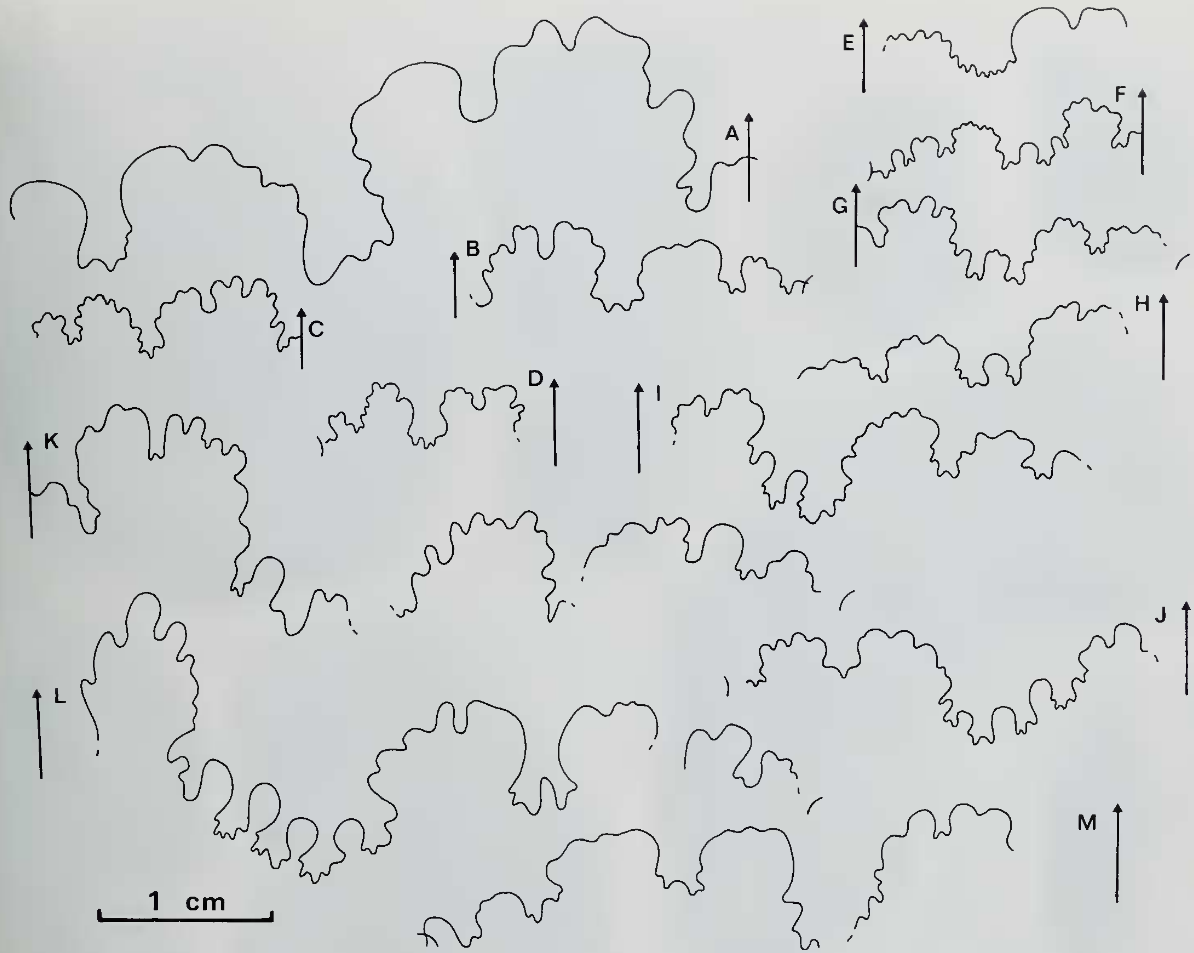

Fig. 19 Sutures in: A–D, *Nigericeras gadeni* (Chudeau), Gadeni Zone, Pindiga Formation. A, C.91222, basal limestone bed, Ashaka Quarry. B, C.91207, north-east of Biu plateau. C, C.91211, Teli. D, C.91212, Teli. E, *Eotissotia simplex* Barber, C.91235, upper Dukul Formation, Dukul. F–K, *Hoplitoides ingens* (von Koenen), upper Dukul Formation, Dukul. F, C.91251; G, C.91250; H, C.91247; I, C.91245; J, C.91248; K, C.91246. L, *Coilopoceras discoideum* Barber, C.91227, Pindiga Formation, Bularaba. M, *Wrightoceras munieri* (Pervinquière), C.91237, upper Dukul Formation, Dukul. All specimens are housed in the British Museum (Natural History), London. × 2·4

dissection of several adult *V. nigeriense* failed to reveal juvenile whorls with the highly bullate umbilical tubercles which are common in these forms.

Vascoceras cf. *evolutum* (Schneegans 1943: 130; pl. 8, fig. 2) is common in the Cauvini Zone at Ashaka and Pindiga; it occurs associated with *Pseudaspidoceras pseudonodosoides* (Choffat). At Dukul the stratigraphically lowest ammonite collected belongs to the latter genus (Fig. 22). This form is conspecific with the '*Pseudaspidoceras* sp.' of Barber (1957: 11; pl. 25, fig. 8) which, while losing all but the umbilical ornament early in ontogeny, shows the robust, rectiradiate ribbing of *P. pseudonodosoides* in its juvenile and middle growth stages. The Dukul specimen occurs below scree levels containing ammonites typical of the Proprium and Nigeriensis Zones (Fig. 28), suggesting a stratigraphical position high in the Cauvini Zone. Barber's material, however, came from Bularaba, where the ammonite-bearing beds begin in the Proprium Zone (see below), indicating that *Pseudaspidoceras* of *pseudonodosoides* type extend into this part of the sequence.

Popoff *et al.* (1986) proposed a 'Zone of *Vascoceras tavense*' for beds at Pindiga and Ashaka making up the lower part of the Cauvini Zone as here defined. As Freund & Raab (1969: 23–24) pointed out, *V. tavense* Faraud (1940: 43; pl. 1, fig. 1; pl. 5, fig. 1; pl. 8, fig. 2) is a very poorly defined species. Berthou *et al.* (1985: pl. 3, figs 11, 12) refigured the corroded holotype photographically and showed its inadequacy as the basis of a new species. They remarked upon similarities with *Spathites* (*Jeanrogericeras*) Wiedmann, 1960 but regarded *V. tavense* as a *nomen dubium*. A Zone of *V. tavense* is not

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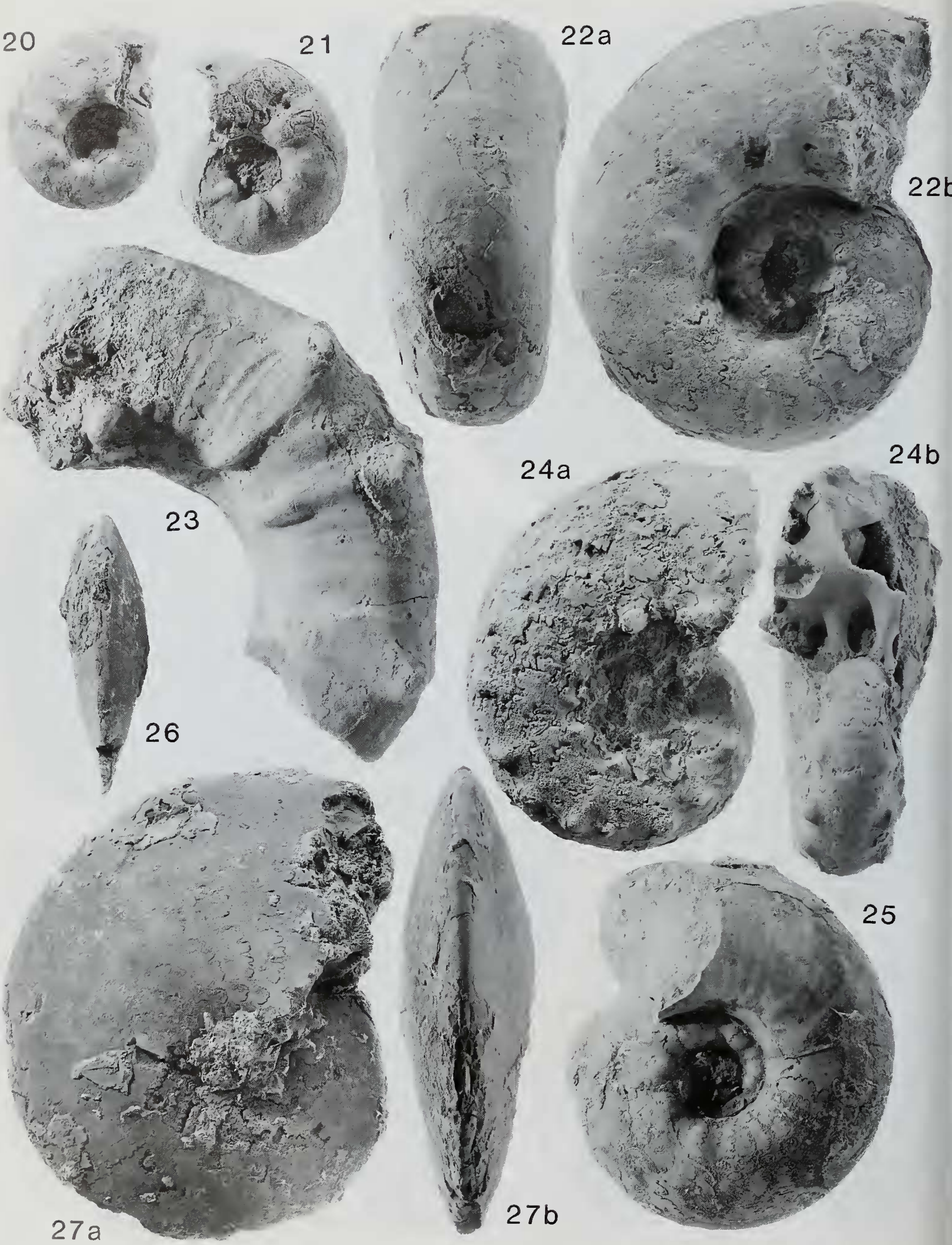
Figs 12–15 *Vascoceras cauvini* Chudeau. Figs 12–14, Pindiga Formation, Ashaka Quarry. Figs 12a, b, C.91272, × 1. Figs 13a, b, C.91271, × 1. Fig. 14, C.91274, × ⅔. Figs 15a, b, Pindiga Formation (Cauvini Zone), Pindiga. C.91278, × 1.

Figs 16–18 *Vascoceras* sp. juv. Fig. 16, Pindiga Formation (Cauvini Zone), Deba Habe. C.91256, × 1. Figs 17–18, Pindiga Formation (Cauvini Zone), Pindiga. Figs 17a, b, C.91263, × 1. Figs 18a, b, C.91264, × 1.

All specimens are housed in the British Museum (Natural History), London.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adopted here; all the *Vascoceras* occurring at these stratigraphical levels can be referred to *V. cauvini*.

The Cauvini Zone can be recognized at Pindiga, Ashaka and Deba Habe. The upper part is probably represented in the lower Dukul Formation at Dukul.

The *Vascoceras proprium* Zone

This zone encompasses the uppermost part of the *Vascoceras bulbosum* Zone and the *Paravascoceras costatum* Zone as applied by Barber (1957) and Popoff *et al.* (1986) (see Fig. 2). Its base is defined at the appearance of *V. proprium* which at Pindiga is the upper 'crystalline limestone' of Barber's (1957: table 3) unit 5. At Ashaka the base occurs at the bottom of unit 5 of Popoff *et al.* (1986: 348).

Paravascoceras costatum (Reyment 1954*a*: 257; pl. 3, fig. 6; pl. 4, fig. 3; pl. 5, fig. 2; text-figs 3a, b, 5), previously employed as a zonal index in north-eastern Nigeria, has recently been listed, along with *Pachyvascoceras* (=*Vascoceras*) *globosum* Reyment (1954*a*: 259; pl. 3, fig. 3; pl. 5, fig. 4; text-figs 3c, 7), as a synonym of *Vascoceras proprium* (Reyment 1954*a*: 258; pl. 5, figs 1a, b; text-figs 3d, 6) by Kennedy *et al.* (1987: 46). The Proprium Zone is condensed at Ashaka and in the region around Gulani and Bularaba (Fig. 1). It contains an enormous array of rather compressed to highly depressed *Vascoceras* in these areas, mainly referred to *V. globosum* and *Paravascoceras costatum* by Barber (1957). These faunas are in need of detailed revision but, in agreement with Kennedy *et al.* (1987), it has not proved possible to distinguish *P. costatum* as a discrete species. It is a variant of *V. proprium* with suppressed umbilical tuberculation but ventral ribbing in the adult stages. *V. cauvini* and *V. nigeriense* extend into the Proprium Zone, along with the juvenile *Vascoceras* mentioned above in connection with the upper part of the Cauvini Zone. *Thomasites gongilensis* appears in the Proprium Zone. The various forms referred to *Paramammites* Furon and *Nigericeras* Schneegans by Barber (1957) occur in the Proprium Zone. They are not, however, typical members of either of these genera. Similar material is common at Ashaka and shows an ornament characteristic of the Euomphaloceratinae Cooper, 1978 in the early and middle growth stages with seven rows of tubercles and much multiplied ventral ribbing. Unlike true *Paramammites* there are marked siphonal tubercles persisting to diameters as high as 70 mm. The suture lacks the square, bifid first lateral saddle typical of *Nigericeras* (Figs 19A–D), its elements being more elongate and the lateral lobe wider, while these forms show stronger and more persistent ornament. They often resemble *Nigericeras ogojaense* Reyment (1955: 62; pl. 13, fig. 6; pl. 14, fig. 3; text-fig. 28) and, to a lesser extent, *N. scotti* Cobban (1971: 18; pl. 9, figs 1–4; pl. 18, figs 1–9; text-figs 15–19). These species also show divergence from the type species, *N. gignouxi* Schneegans, 1943, in the characters mentioned above. Finally, Wozny & Kogbe (1983) reported *Metengonoceras dumbli* from their *Paravascoceras costatum* Zone (= Proprium Zone as employed here), although in the present study it has been found only in the Gadeni Zone.

The Proprium Zone can be recognized at Pindiga, Ashaka, Balbaya, Gulani and Bularaba (Fig. 1). Characteristic members of its fauna are present in surface scree at Deba Habe and Dukul. In the area between Balbaya and Bularaba it makes up the basal part of the limestone-bearing beds.

The *Pseudotissotia nigeriensis* Zone

As employed here, the *Pseudotissotia nigeriensis* Zone corresponds with that of Popoff *et al.* (1986), its base being marked by the appearance of *P. nigeriensis. Thomasites gongilensis* reaches its acme in the lower half of this zone where it may occur in very large numbers. Wozny & Kogbe (1983) proposed a 'Zone of *Gombeoceras gongilense*' for these horizons. As noted by Popoff *et al.* (1986), however, *Thomasites* [= *Gombeoceras*] *gongilensis* occurs both lower and higher and, following these authors, a separate zone is not distinguished here. At Pindiga and Ashaka the acme of *T. gongilensis* coincides with the occurrence of *Pseudaspidoceras* of *P. flexuosum* Powell, 1963 type (Figs 23, 24). *Vascoceras proprium* extends into the lower part of the Nigeriensis Zone, while *Neoptychites*, *Choffaticeras* and *Mammites*? occur as rarities. *Eotissotia simplex* Barber is common in its upper part. At several localities, notably Dukul, the more compressed and smoother varieties of *Pseudotissotia nigeriensis* occur higher in the zone, the earlier members resembling, indeed merging with, *Thomasites gongilensis*.

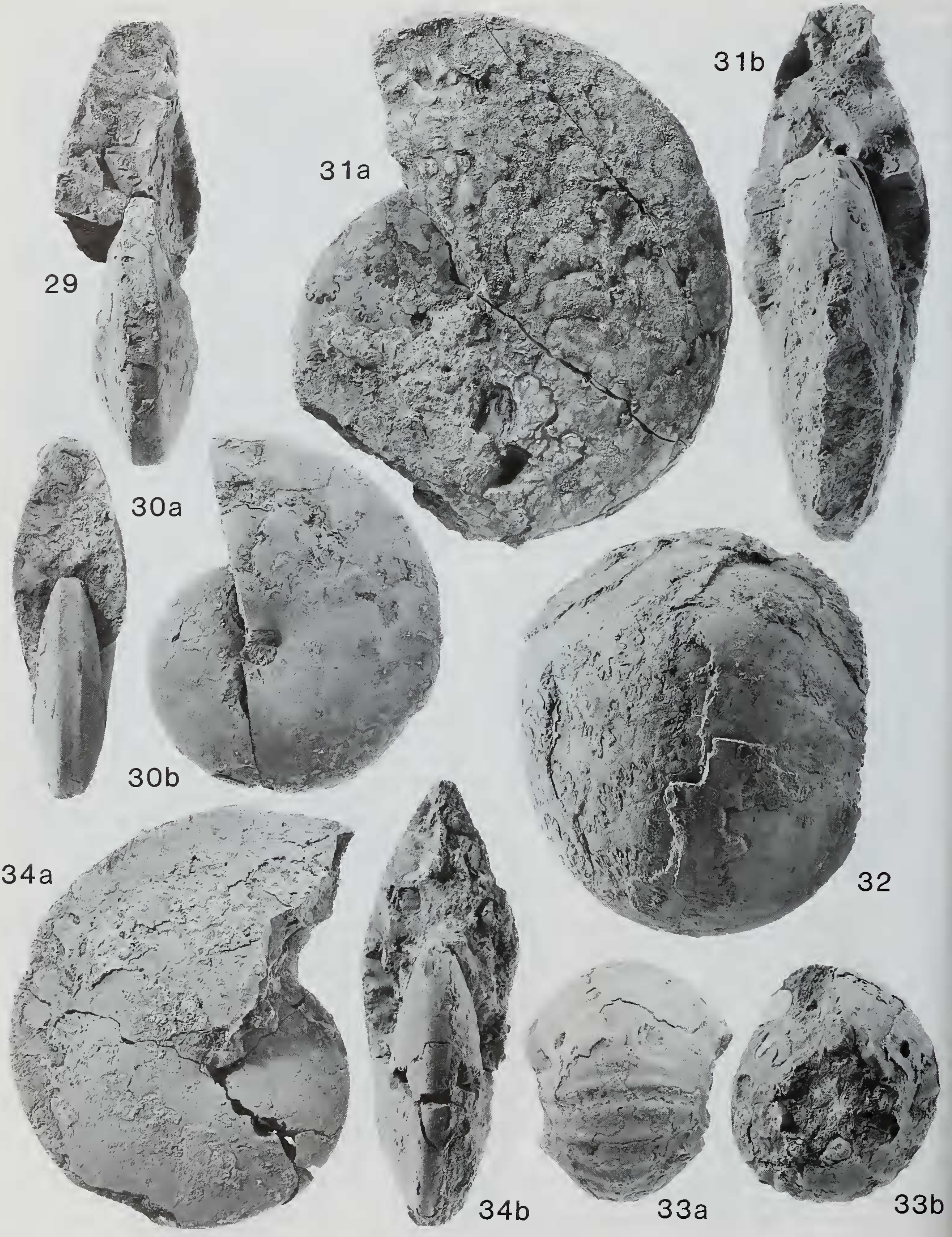
The Nigeriensis Zone can be recognized at Pindiga, Ashaka, Deba Habe, Dukul, Balbaya, Gulani and Bularaba.

The *Wrightoceras wallsi* Zone

A 'Zone of *Wrightoceras wallsi*' was first proposed for north-eastern Nigeria by Reyment (1965) but was intended to include the entire sequence from Gadeni to Wallsi Zone as employed here. Popoff *et al.* (1986) used the zone in a more restricted sense for beds including the upper part of the range of *Pseudotissotia nigeriensis*. Wherever the stratigraphical relationships have been seen (Pindiga, Ashaka, Deba Habe, Dukul and Bularaba), *W. wallsi* occurs only at these high levels. Apart from the index species, the Wallsi Zone contains *P. nigeriensis* and *Eotissotia simplex*, both of which are common.

Popoff *et al.* (1986) proposed a 'Zone of *Choffaticeras barjonae*' for the uppermost ammonite-bearing beds at Pindiga and a 'Zone of *Fagesia* n. sp. aff. *spheroidalis* Pervinquière' for those at Ashaka. These zones were correlated with one another even though, in fact, they contain no ammonites in common. A form similar to *Fagesia superstes* var. *spheroidalis* Pervinquière (1907: 324; pl. 20, figs 3a, b, 4, A) also occurs at Dukul (see below, Figs 32, 33) but in beds younger than those

Figs 20, 21 *Vascoceras* sp. juv. Fig. 20, Pindiga Formation (Cauvini Zone), Pindiga. C.91262, × 1. Fig. 21, Pindiga Formation (Cauvini Zone), Deba Habe. C.91257, × 1.
Figs 22a, b *Pseudaspidoceras* cf. *pseudonodosoides* (Choffat). Lower Dukul Formation, Dukul. C.91232, × 1.
Figs 23, 24 *Pseudaspidoceras* cf. *flexuosum* Powell. Fig. 23, Pindiga Formation (lower part of Nigeriensis Zone), Ashaka Quarry. C.91275, × $\frac{3}{4}$. Figs 24a, b, Pindiga Formation (lower part of Nigeriensis Zone), Pindiga, C.91276, × 1.
Fig. 25 *Vascoceras nigeriense* Woods. Pindiga Formation (Proprium Zone), Ashaka Quarry. C.91277, × $\frac{3}{4}$.
Figs 26, 27 *Hoplitoides ingens* (von Koenen). Upper Dukul Formation, Dukul. Fig. 26, C.91247, × 1. Figs 27a, b, C.91246, × 1.
All specimens are housed in the British Museum (Natural History), London.


29
30a
30b
31a
31b
32
33a
33b
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34b

at Ashaka. Nowhere else in the region have the index species of Popoff *et al.* been found. *Wrightoceras wallsi* persists throughout their Zone of *Fagesia* n. sp. at Ashaka. Their Barjonae Zone at Pindiga also contains species (*Eotissotia simplex* and *Thomasites gongilensis*) persisting from below. These two zones cannot yet be applied over north-eastern Nigeria as a whole and they are not differentiated here from the Wallsi Zone. It is, however, possible that in the future a discrete zone might be recognized at this stratigraphical level.

The Wallsi Zone outcrops at Pindiga, Ashaka, Deba Habe, Dukul and Bularaba. The index species has also been reported from Gulani and south-east of Numan (Barber 1957, Carter *et al.* 1963).

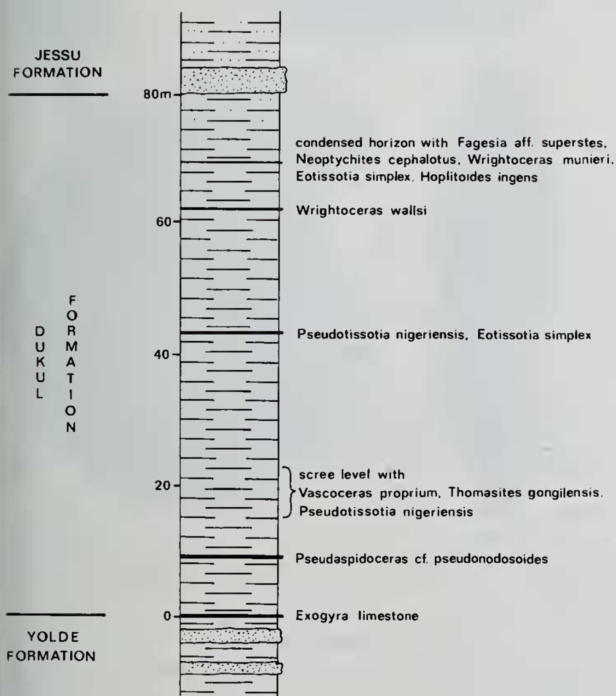


Fig. 28 Stratigraphical section of the Dukul Formation at Dukul, showing the positions of the main limestone beds and their ammonite faunas.

Younger Turonian faunas

At its type locality, Dukul village (Fig. 1), the upper part of the Dukul Formation includes a 10-cm calcareous bed overlying the Wallsi Zone (Fig. 28). This bed contains phosphatic pebbles and laths, comminuted vertebrate remains and phosphatized gastropod moulds. Numerous ammonites also occur, with the exception of one specimen of *Fagesia*, all those recovered being wholly or partially phosphatized and some showing signs of reworking. The fauna includes rare *Eotissotia simplex* (Figs 19E, 37) and *Neoptychites cephalotus* (Courtiller) (Fig. 31) with more common *Wrightoceras munieri* (Pervinquière) (Figs 19M, 29, 30). Also present are scarce *Fagesia* (Figs 32, 33), similar to *F. superstes* (Kossmat 1897: 26; pl. 6, fig. 1) in the early whorls and later developing a highly globular shell shape like that in *F. superstes* var. *spheroidalis* Pervinquière. The Nigerian form, however, has peculiar, highly clavate umbilical tubercles, in places forming an almost continuous flange on the umbilical shoulder. The commonest ammonite in this fauna, though, is *Hoplitoides ingens* (von Koenen, 1897) (Figs 19F–K, 26, 27, 34). The timing of the transition from a truncated to an acute venter is variable in this material but all the variants are matched by specimens of *H. ingens* in a fauna from Wadatta in central Nigeria described by Reyment (1955: 79–81). Being highly condensed, no formal biostratigraphical unit is proposed for this bed; its fauna may eventually be found to span more than one biozone. It is, however, of great significance in allowing an upper age limit to be placed upon the Wallsi Zone (see below).

To the north of Bularaba (Bularafa) (Fig. 1) the Proprium to Wallsi Zones are present in the main limestone development of the Pindiga Formation. The immediately overlying strata are not exposed but some distance above the Wallsi Zone thin shelly limestones and calcareous sandstones occur containing *Coilopoceras discoideum* Barber, 1957 (Figs 19L, 35, 36) and *Placenticeras* aff. *cumminsi* Cragin, 1893 (Fig. 38). An assemblage zone characterized by these two ammonites is here proposed for these beds. *C. discoideum* is otherwise known only from the Mona region (Barber 1957, Grant 1965) some 150 km to the south (Fig. 1).

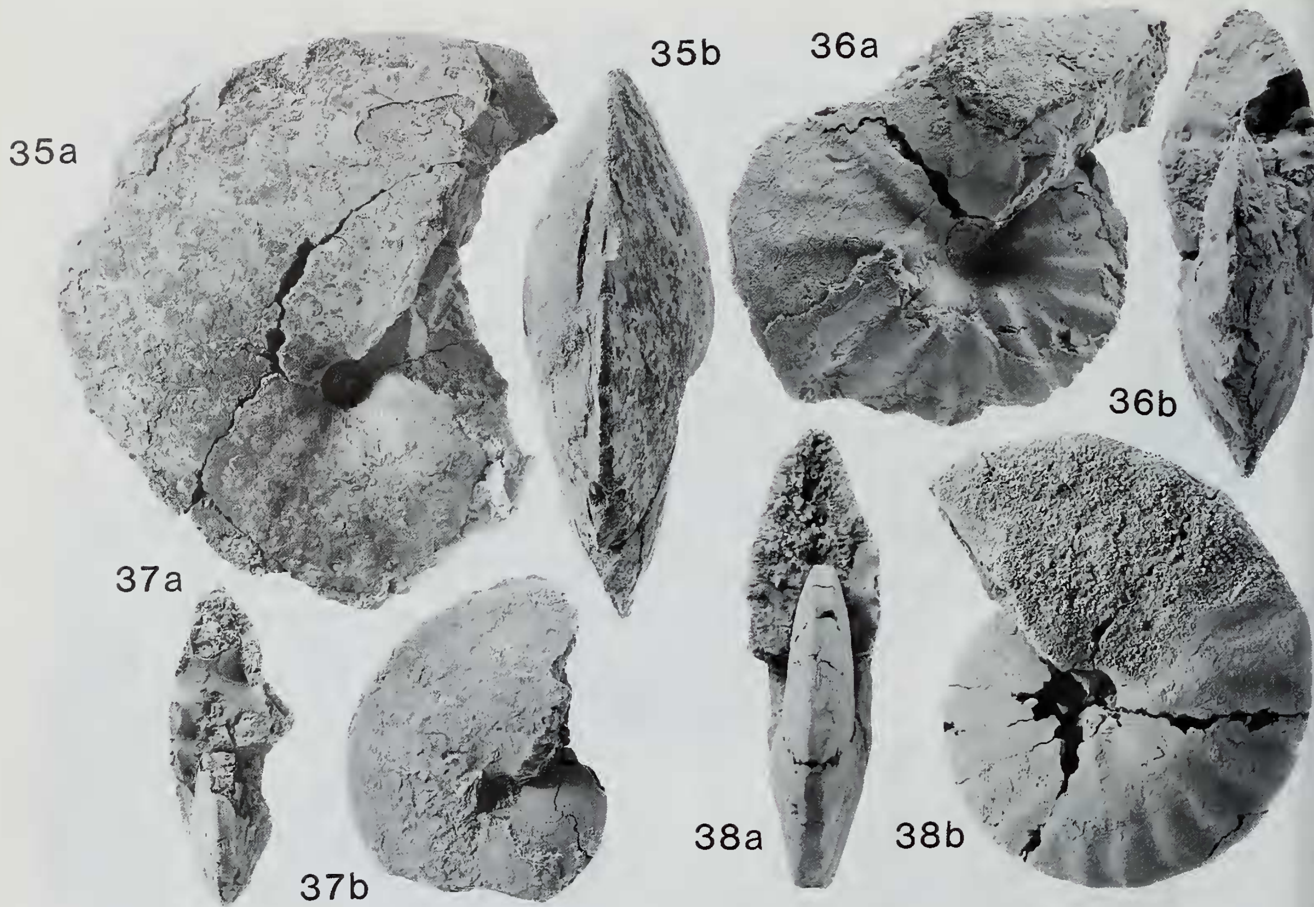
AGES AND CORRELATION

Correlation outside Nigeria

The Nigerian faunas discussed here are predominantly composed of members of the characteristically Tethyan family Vascoceratidae. Ammonite faunas of the Upper Cenomanian and Lower Turonian in north-west Europe, including the type areas, are, on the other hand, mainly Boreal in nature with the Mammitinae especially important. Problems of provinciality at these levels in the Cretaceous are well known. Sufficient data, however, are accumulating from various parts of the world to allow a reasonably reliable correlation with northern Nigeria.

The oldest ammonite-bearing beds in north-eastern Nigeria, the *Nigericeras gadeni* Zone, contain, west of Wajari, *Metoicoceras geslinianum*. These beds can therefore be firmly assigned to the Upper Cenomanian as previously suggested by Hancock & Kennedy (1981), Wozny & Kogbe (1983), Popoff *et al.* (1986) and Kennedy *et al.* (1987). They correlate with the *M. geslinianum* Zone of north-west Europe, now included in the Cenomanian (see, for example, Kennedy & Juignet 1973, Wright & Kennedy 1981, Hancock & Kennedy 1981). There are no ammonite faunas in north-eastern Nigeria of age equivalent to those with *Neolobites* Fischer which underlie beds of Geslinianum Zone age in many parts of the

Figs 29, 30 *Wrightoceras munieri* (Pervinquière). Upper Dukul Formation, Dukul. Fig. 29, C.91236, × ¾. Figs 30a, b, C.91237, × 1.
Figs 31a, b *Neoptychites cephalotus* (Courtiller). Upper Dukul Formation, Dukul. C.91229, × ¾.
Figs 32, 33 *Fagesia* aff. *superstes* (Kossmat). Upper Dukul Formation, Dukul. Fig. 32, C.91231, × ¾. Figs 33a, b, C.91230, × 1.
Figs 34a, b *Hoplitoides ingens* (von Koenen). Upper Dukul Formation, Dukul. C.91245, × 1.
All specimens are housed in the British Museum (Natural History), London.



Figs 35, 36 *Coilopoceras discoideum* Barber. Pindiga Formation (Discoideum Zone), Bularaba. Figs 35a, b, C.91227, × $\frac{3}{4}$. Figs 36a, b, C.91226, × 1.
Figs 37a, b *Eotissotia simplex* Barber. Upper Dukul Formation, Dukul. C.91235, × 1.
Figs 38a, b *Placenticeras* aff. *cumminsi* Cragin. Pindiga Formation (Discoideum Zone), Bularaba. C.91233, × 1.
All specimens are housed in the British Museum (Natural History), London.

world, particularly Tethyan areas (see, for example, Greigert & Pougnet 1967, Freund & Raab 1969, Wiedmann 1960, Busson 1965, 1972, Kennedy & Juignet 1981, Amard *et al.* 1981, Berthou 1984).

The age of the *Pseudotissotia nigeriensis* and *Wrightoceras wallsi* Zones has been the subject of some disagreement. Barber (1957), Hancock & Kennedy (1981), Wozny & Kogbe (1983) and Kennedy *et al.* (1987) dated them Early Turonian, but Popoff *et al.* (1986) preferred a Middle Turonian age. The condensed horizon containing, amongst others, *Hoplitoides*, which occurs above the Wallsi Zone at Dukul, allows an upper age limit to be suggested for this zone. *Wrightoceras munieri* was used in Spain by Wiedmann (1960, 1979) and Wiedmann & Kauffman (1978) as an index species for the earliest Middle Turonian beds. Since *Mammites nodosoides* (Schlüter) is an associated species, however, Kennedy (1985) suggested that *W. munieri* should be assigned to the Lower Turonian in Spain. In Texas *W. munieri* occurs as low as the basal Turonian *Pseudaspidoceras flexuosum* Zone (Kennedy *et al.* 1987), while it is one of the first species to appear in the Venezuelan Turonian (Renz 1982). *Neoptychites cephalotus* is an early mid-Turonian species in the type area in France (Amédro *et al.* 1982, Robaszynski *et al.* 1983) but occurs in the lower part of the Lower Turonian in the western interior of the United States (Cobban & Scott 1972, Cobban 1984) and southern Nigeria (Zaborski 1987). *Fagesia superstes* also occurs in the Lower Turonian of the western interior (Cobban 1984) and Portugal (Berthou & Lauverjat 1979). *Eotissotia simplex* persists from the underlying Nigeriensis and Wallsi Zones at Dukul. Although *Hoplitoides latefundatus* Zaborski, 1987 occurs in the upper Lower Turonian of southern Nigeria, this genus is mainly of Middle Turonian age (Cobban & Hook 1980, Kennedy & Wright 1984). In the western interior of the United States it appears in the early Middle Turonian (Cobban 1984). In Nigeria *H. ingens* is thought to be characteristic of early Middle Turonian beds (Reyment 1978), the main occurrence of the genus being at Wadatta in the central part of the country.

This condensed fauna therefore contains elements which range from Lower to early Middle Turonian. Allix (1982) regarded the top of the Dukul Formation as basal Middle Turonian and an age very close to the Lower–Middle Turonian boundary is also suggested here. The Wallsi Zone below is almost certainly of late Early Turonian age, contrary to the opinion of Popoff *et al.* (1986). Further evidence to this effect is that *Choffaticeras barjonae*, proposed by these authors as the index species for a zone above limestones with *Wrightoceras wallsi* at Pindiga, occurs in beds assigned to the

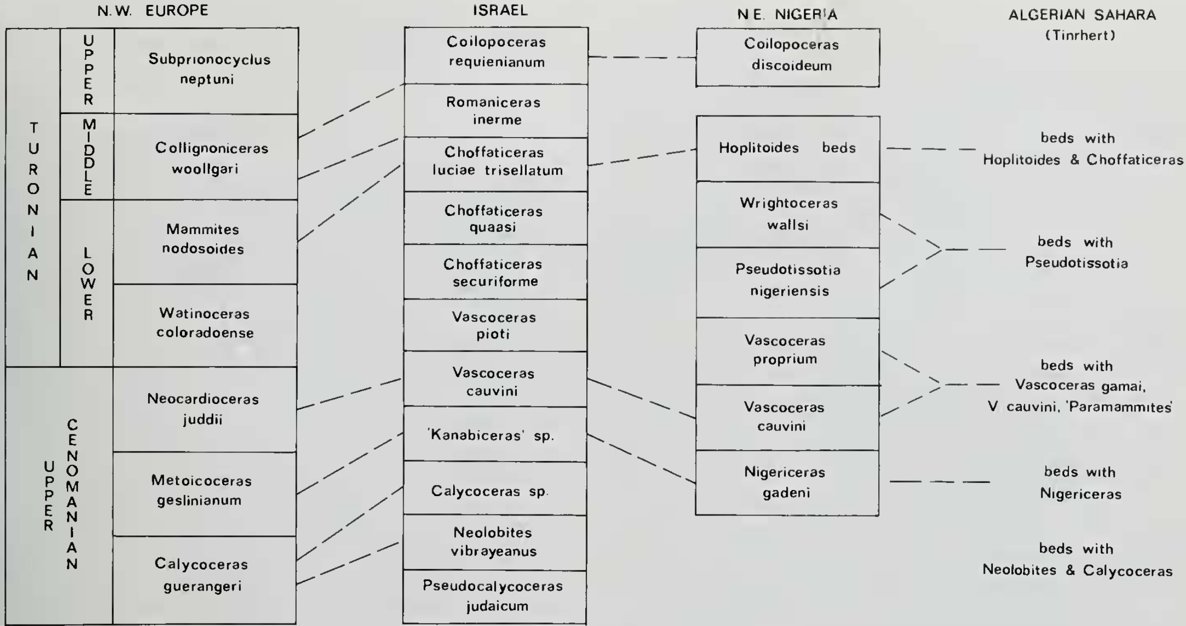


Fig. 39 Correlation of the Upper Cenomanian and Turonian in north-eastern Nigeria with the Algerian Sahara and Israel. Correlation between Israel and north-west Europe follows Lewy *et al.* (1984) and Kennedy (1985).

Lower Turonian in Portugal (Berthou 1984). Thus *Pseudotissotia* occurs considerably earlier in Nigeria than in France where the type species, *Ammonites galliennei* d'Orbigny, is of late Middle Turonian age (Kennedy *et al.* 1979, Amédro *et al.* 1982).

The Gadeni to Wallsi Zones in Nigeria therefore span an interval equivalent to the *Metoicoceras geslinianum* to *Mammites nodosoides* Zones in north-west Europe (Fig. 39). The chief remaining difficulty is the location of the Cenomanian–Turonian boundary. The Cauvini Zone in Nigeria is referrable to the Cenomanian. *Vascoceras cauvini* occurs in association with *M. geslinianum* over part of its range in Israel (Lewy *et al.* 1984). The latter species is known only from the Gadeni Zone in Nigeria, but, as noted previously, possible examples of *V. cauvini* are present in this zone. *V. cauvini* is an Upper Cenomanian species in the western interior of the United States (Cobban 1984). *Pseudaspidoceras pseudonodosoides*, common in the Cauvini Zone in Nigeria (see above, Popoff *et al.* 1986), occurs in the equivalent zone in Israel and in the uppermost Cenomanian *Neocardioceras juddii* (Barrois & Guerne) Zone of the western interior (Cobban 1984).

The overlying Proprium Zone contains, in its lower part, *Vascoceras cauvini* and *V. nigeriense*. The latter is very similar in its adult stages to *V. gamai* Choffat, 1898 (see Berthou *et al.* 1985 for a review), a species having its acme in the Upper Cenomanian. The Proprium Zone also contains the earliest examples of *Thomasites gongilensis*, a species which is known from the highest Cenomanian *Neocardioceras juddii* Zone and just below in southern England (Wright & Kennedy 1981) and in Brazil at a similar stratigraphical level (Bengtson 1983). Wozny & Kogbe (1983) also recorded *Metengonoceras dumbli*, a Cenomanian species (see Kennedy *et al.* 1981, Kennedy & Juignet 1984), from low in the Proprium Zone. In the lower part of the Nigeriensis Zone above, *Pseudaspidoceras* of *P. flexuosum* type occur at the level in which *Thomasites gongilensis* reaches its acme. The appearance of *P. flexuosum* is widely proposed as a marker for the base of the Turonian stage (Hancock 1984, Cobban 1984, Birkelund *et al.* 1984, Kennedy *et al.* 1987). As suggested by Hancock & Kennedy (1981) and Kennedy *et al.* (1987), the Cenomanian–Turonian boundary lies either within, or quite possibly at the top of, the Proprium Zone.

The stratigraphical position of *Coilopoceras discoideum* in Nigeria has previously seemed to be incongruous. It has, until now, been known only from the Mona region (Fig. 1), according to Barber (1957: 59), 'several hundred feet below the vascoceratid beds' (= Dukul Formation). This would imply a position well down in the Cenomanian. Grant (1965), on the other hand, believed it to be younger, occurring sometimes alone but in places with a typically early Turonian association of *Thomasites*, *Pseudotissotia*, *Vascoceras* and *Pseudaspidoceras*. He was, however, unable to recognize a detailed ammonite biostratigraphy. Both of these ages are at variance with current knowledge. Kennedy & Wright (1984) cast doubt on the reported occurrence of *Coilopoceras* in the Cenomanian of North Africa (see Pervinquière 1910). In the western interior of the United States the genus appears in the upper Middle Turonian but is mainly Late Turonian (Cobban & Hook 1980, Cobban 1984). In France its distribution is similar, from the *Romaniceras* (*R.*) *deverianum* (d'Orbigny) Zone (see Amédro *et al.* 1982), equivalent to the upper part of the *Collignoniceras woollgari* (Mantell) Zone of Kennedy *et al.* (1982) and Kennedy (1984) which these authors regarded as Middle Turonian, to the Upper Turonian *Subprionocyclus neptuni* (Geinitz) Zone. At Bularaba no continuous section is available but *Coilopoceras discoideum* certainly occurs some distance above the Wallsi Zone. Its only known associated ammonite is *Placenticeras* aff. *P. cumminsi*, a species found in the Lower and throughout the Middle Turonian of the western interior (Cobban 1984). At Bularaba there is no reason to believe that *Coilopoceras* appears unusually early and, as elsewhere, it can be assigned

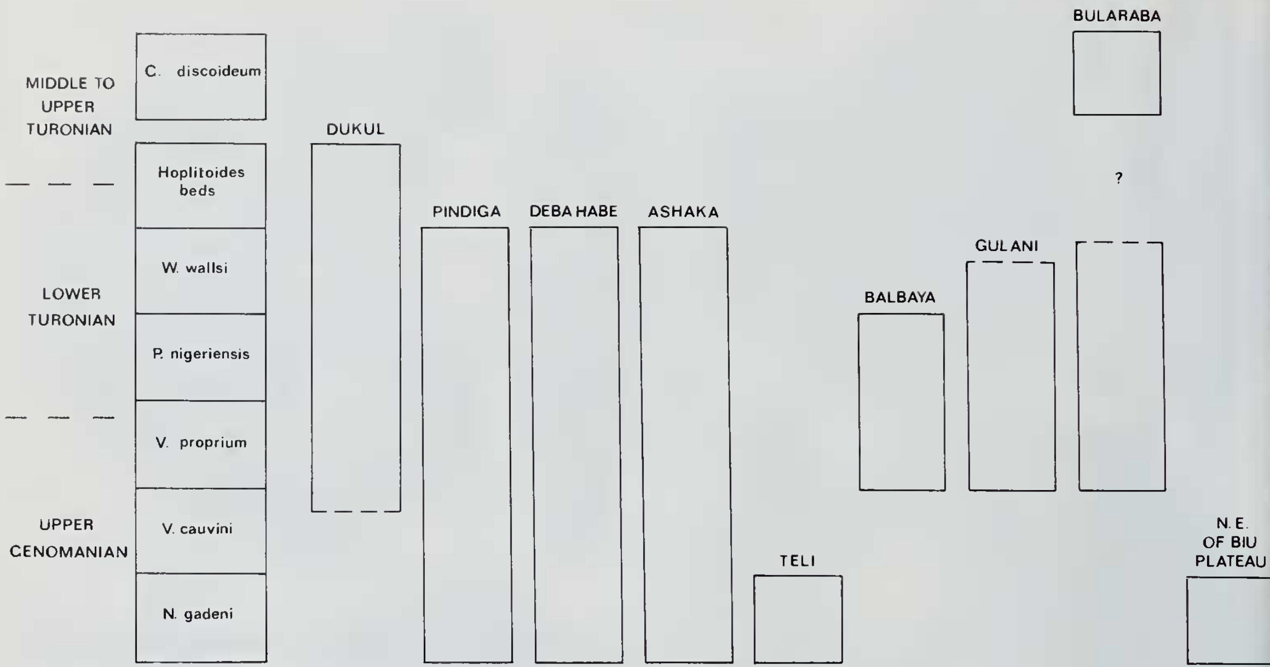


Fig. 40 Geographical distribution of ammonite biozones in north-eastern Nigeria. In most cases these biozones correspond with the limestone-bearing lithofacies.

to the upper Middle or Upper Turonian. Although the latter is more likely, a definite decision as to which is not possible in the current state of knowledge. As regards the occurrence of *C. discoideum* at Mona, it is significant that Lawal (1982) and Lawal & Moullade (1986) identified both Upper Turonian and Coniacian microfloras in the immediate area.

Whilst there are problems of provinciality involved in correlating the north-eastern Nigerian faunas with those of Boreal regions, comparison within the Tethyan province has been complicated by varying taxonomic opinions. The most straightforward correlation is probably with Israel (see Freund & Raab 1969, Lewy & Raab 1978, Lewy *et al.* 1984, and Fig. 39 herein for an ammonite biostratigraphy). There are no biostratigraphical equivalents in north-eastern Nigeria of the Israeli zones below that of '*Kanabiceras*' (properly *Euomphaloceras* Spath). The '*Kanabiceras*' Zone itself can be correlated with the Nigerian Gadeni Zone; both contain *Metoicoceras geslinianum* while *Nigericeras* of *N. gadeni* type (see Freund & Raab 1969: 19; pl. 2, fig. 1; text-fig. 40) occurs in the lower part of the Israeli zone. In the lower part of its range *Vascoceras cauvini* occurs alongside *M. geslinianum* in Israel and in Nigeria possible examples of *V. cauvini* are known from the Gadeni Zone at Pindiga. The *V. cauvini* zones in the two countries can also be correlated because of the occurrence of the index species and *Pseudaspidoceras* of *P. pseudonodosoides* type in both. The succeeding *Vascoceras pioti* (Peron & Fourtau), *Choffaticeras securiforme* (Eck) and *C. quaasi* (Peron) Zones in Israel cannot at present be directly correlated with Nigeria owing to a lack of common elements; there is only a record of *Pseudotissotia nigeriensis* from the Pioti Zone (Freund & Raab 1969: 50). The *Choffaticeras luciae trisellatum* Freund & Raab Zone in Israel, however, contains an assemblage including *Neoptychites cephalotus* and *Hoplitoides*, suggesting that it is broadly equivalent to the *Hoplitoides*-bearing bed at Dukul. The highest Turonian zone recognized in Israel is that of *Coilopoceras requienianum* (d'Orbigny) of late Middle or Late Turonian age; it can be regarded as broadly contemporaneous with the *C. discoideum* Zone in Nigeria. A noteworthy difference between the Lower Turonian of Israel and that of northern Nigeria, however, is the scarcity of *Choffaticeras* and corresponding abundance of *Pseudotissotia* and *Eotissotia* in the latter region. Interestingly, *Eotissotia simplex* is sometimes homoeomorphic with *Choffaticeras*; it may display a tricarinate venter in its middle growth stages and, more commonly, subdivision of most or all of the sutural saddles.

The Cenomanian–Turonian ammonite succession of the Algerian Sahara (see Busson 1965, 1972, Lefranc 1978, Amard *et al.* 1978, 1981; Fig. 39 here) is broadly similar to that in north-east Nigeria. There are, again, no Nigerian equivalents of the *Neolobites*-bearing beds in Algeria which include the upper parts of the ranges of *Calycoceras* Hyatt, *Eucalycoceras* Spath and *Pseudocalycoceras* Thomel and the lower part of the range of *Nigericeras* (Amard *et al.* 1978). The overlying beds in Algeria contain numerous *Nigericeras* without *Neolobites*, these horizons being equivalent to the earliest ammonite-bearing beds in northern Nigeria. The succeeding strata contain, amongst others, *Vascoceras cauvini*, *Paramammites laffittei* Collignon (1965: 186; pl. A, fig. 2) and *P. subtuberculatus* Collignon (1965: 187; pl. A, fig. 3), the last two being similar to and possibly conspecific with the various forms from Nigeria referred to *Paramammites* by Barber (1957). Next are beds with, in places, numerous *Pseudotissotia* (*Bauchioceras*) *nigeriensis* var. *egredians* Collignon (1965: 188; pl. H, fig. 1) and *P.* (*B.*) *bussoni* Collignon (1965: 190; pl. H, fig. 2), both, according to Hirano (1983), probable synonyms of *P. nigeriensis*. Collignon's figured specimens are especially close to microconchs of *P. nigeriensis* found at Deba Habe. In Algeria younger Turonian beds contain

Hoplitoides and, in the northern Tademaït region, *Coilopoceras* (Collignon & Lefranc 1974). Again *Choffaticeras* occurs in some numbers at these higher levels.

Correlation within Nigeria

In north-eastern Nigeria ammonites are almost exclusively confined to calcareous horizons and are therefore of biostratigraphical use only in formations containing such lithofacies. As shown in Fig. 40, the Cenomanian and Turonian limestones occur at various stratigraphical levels from place to place, as was pointed out by Lawal (1982) and Lawal & Moullade (1986). At Ashaka, Deba Habe and Pindiga limestone-bearing sequences ranging from the Gadeni to Wallsi Zone are present. At Dukul the Gadeni Zone has not been recognized. While the Dukul Formation includes an *Exogyra*-rich limestone at its base, the earliest ammonite present, *Pseudaspidoceras* cf. *pseudonodosoides*, occurs some 10 m higher in what is probably the upper part of the Cauvini Zone. The top of the Dukul Formation is a little younger than the highest ammonite-bearing beds at Pindiga, Deba Habe and Ashaka; no equivalent of the *Hoplitoides* fauna from Dukul is known at these localities. At Teli and north-east of the Biu plateau the Gadeni Zone alone is present. In the region between Balbaya and Bularaba the limestones of the Pindiga Formation belong to the Proprium Zone at their base. At Balbaya only ammonites typical of the overlying Nigeriensis Zone have otherwise been found but at Bularaba the main limestone body extends up into the Wallsi Zone. This species has also been reported from Gulani (Barber 1957), where the Nigeriensis Zone is also present. Apart from Mona, the Discoideum Zone is known only from Bularaba; but the strata intervening between it and the Wallsi Zone, and any ammonites they contain, are unknown.

Apart from varying in age, the limestone-bearing sequences differ markedly in thickness from place to place. In the Pindiga–Gombe–Deba Habe area variable, but consistently large, thicknesses are present. The Pindiga Formation here consists of a lower limestone-shale member and an upper shale member. The limestones, frequently marly, vary from a few cm to about 2 m in thickness. Their upper surfaces often mark minor sedimentary discontinuities. Around Pindiga village borehole records indicate thicknesses of 168 m, 294 m, and 330 m for the Pindiga Formation (Popoff *et al.* 1986). Estimates for the limestone-shale member vary: 60 m (Popoff *et al.* 1986), 80 m (Barber 1957), approximately 100 m (Wozny & Kogbe 1983). This last figure is probably closest to the true thickness. At Gombe town the limestone-shale member totalled about 65 m in one borehole (Thompson 1958, Carter *et al.* 1963: 49). To the south, at Kumo, the Pindiga Formation reaches nearly 800 m, the limestone-bearing part being in excess of 100 m in thickness (Lawal 1982, Lawal & Moullade 1986). At Deba Habe the limestone-shale member makes up the greater part of the Pindiga Formation, being about 100 m thick. At Dukul, the Dukul Formation is of comparable thickness, approximately 80 m, the formation again consisting mainly of shales, the limestones occurring as thin bands a few tens of cm in maximum thickness. At Ashaka the ammonite-bearing sequence is of intermediate thickness, approximately 20 m, the lower 9 m consisting mainly of massive limestones, the upper part shales with thinner interbedded limestones (see Wozny & Kogbe 1983, Popoff *et al.* 1986). North-east of the Biu plateau, on the other hand, the Gadeni Zone is represented by less than 1 m of hard, nodular limestone. The situation at Teli is comparable, though the Gadeni Zone may be slightly thicker. Between Balbaya and Bularaba the ammonite-bearing beds consist of condensed limestone sequences in which argillaceous and marly horizons are of subsidiary importance. At Balbaya the sequence is barely in excess of a couple of metres. It is rather thicker at Gulani and Bularaba but even here seems to be considerably less than 10 m, though no definite figures are available. In this region lithologies more closely resemble those at Ashaka than those in the Pindiga–Gombe area. Popoff *et al.* (1986: 357) found little purpose in separating the Gongila Formation and the overlying Fika Shale (see Carter *et al.* 1963) from the Pindiga Formation. This view is supported here, though Popoff *et al.* also suggested that the Dukul Formation might also be regarded as synonymous. This proposal is less tenable as the Upper Cretaceous sequence, at least in the eastern part of the Dadiya Syncline, is distinctive. In this region a sequence mainly comprising sands and silts (the Jessu Formation) separates the Dukul Formation from another major limestone-shale development of Coniacian age, the Sekule Formation (see Carter *et al.* 1963). Shales (the Numanha Shale) and sandstones (the Lamja Sandstone) complete the sequence, both being lateral equivalents of the Sekule Formation (see Petters 1978, Enu 1980, Allix 1982, Odebode 1987).

Clearly local subsidence history has had a profound effect on the lithological character and thickness of the Upper Cenomanian and Lower Turonian deposits in north-eastern Nigeria. During the Early Turonian the region between Balbaya and Bularaba seems to have been a relatively stable shelf area characterized by almost continuous limestone deposition. At Teli and north-east of the Biu plateau such conditions persisted for only a brief period during the Late Cenomanian. The Pindiga–Gombe–Deba Habe region, however, was characterized by strong subsidence virtually throughout Late Cenomanian and Early Turonian times, though the upper parts of the limestone beds here, sometimes rich in glauconite and containing reworked ammonites, often mark minor sedimentary discontinuities. Similar conditions prevailed to the south-east at Dukul where limestone deposition commenced a little later and persisted a little longer. At Ashaka limestone deposition characterized the Late Cenomanian but shales became the dominant lithology during the Early Turonian.

Allix & Popoff (1983) and Popoff *et al.* (1983) showed how, during the Early Cretaceous, sedimentation in north-eastern Nigeria was strongly influenced by faults, at first trending E–W and later NE–SW. Benkhelil (1982), Benkhelil & Robineau (1983) and Maurin *et al.* (1986) also stressed the importance of the latter structures, which they believed to be related to the South Atlantic transform fault system, during the Late Cretaceous. Sinistral strike-slip movement produced localized uplifted blocks and more extensive subsiding areas, 'pull-apart' or 'rhomb basins'. A number of such basins were identified by Maurin *et al.* (1986: fig. 12). Of these, the Pindiga and Lau Basins displayed the greatest rates of subsidence during the Late Cenomanian and Early Turonian.

Vascoceratid-dominated ammonite assemblages also occur in central and southern Nigeria. Particularly noteworthy are the Keana area with *Vascoceras nigeriense*, *V. proprium*, *Thomasites gongilensis*, *Pseudotissotia nigeriensis*, *Wrightoceras wallsi* and *Neoptychites* sp. (Offodile & Reyment 1976); and Ezillo with *Vascoceras*, *Fagesia*, *Thomasites gongilensis*, *T. koulabicus* (Kler), *Pseudotissotia nigeriensis*, *Wrightoceras* *wallsi* and *W*. cf. *munieri* (Zaborski 1987). Nowhere, however, is a detailed biostratigraphy available and the ammonite biozones applicable in the north-east cannot, as yet, be recognized outside that region. At Atom, near Makurdi, faunas including *Wrightoceras wallsi*, *Hoplitoides ingens*, *H. gibbosulus* (von Koenen) and *Mammites* spp. are present (Kogbe *et al*. 1978) but, again, the detailed stratigraphical relations of these forms are unclear. A little to the south, however, in the Icheri River near Igumale a fauna containing *Hoplitoides ingens* and *Neoptychites* (?)*cephalotus* overlies beds with *Wrightoceras wallsi* (Reyment 1955: 99), recalling the situation at Dukul. Furthermore, at Wadatta, immediately west of Makurdi, a diverse *Hoplitoides–Mammites–Benueites–Kamerunoceras* fauna (see Reyment 1955) is underlain by vascoceratid-bearing beds (Reyment 1978).

It should finally be noted that there is a marked change in both litho- and biofacies in the Lower Turonian around Lokpanta in southern Nigeria (see Zaborski 1987). Here black shales contain ammonites of boreal character. Basal Turonian beds characterized by *Watinoceras* spp. are overlain by a *Mammites nodosoides* Zone fauna containing *Hypophylloceras* sp., *Pachydesmoceras denisonianum* (Stoliczka), *Kamerunoceras puebloense* (Cobban & Scott), *Mammites nodosoides*, *Neoptychites cephalotus*, *Vascoceras venezolanum* Renz, *Paramammites polymorphus* (Pervinquière), *Fagesia catinus* (Mantell), *Hoplitoides latefundatus* Zaborski and *Herrickiceras*? sp. These black shales are, in the main, the age equivalents of the Nigeriensis and Wallsi Zones in the north-east of the country.

PALAEOBIOGEOGRAPHY

The palaeobiogeographical significance of the ammonite faunas of northern Nigeria has, in the past, often been difficult to assess as it had seemed that many of the forms present were endemic to the region. In opposition to the prevailing view (see Reyment 1980 for a review), Petters (1978) doubted that the northern Nigerian region was in direct connection with the trans-Saharan seaway during the Late Cretaceous. Popoff *et al*. (1986), however, showed that many of the Nigerian ammonite species are also known in the Saharan countries and elsewhere. Similarity is especially close in the Upper Cenomanian where *Metengonoceras*, *Nigericeras gadeni* and *Vascoceras cauvini* are important elements of the faunas in both north-eastern Nigeria and the Damergou area of Niger to the north (Chudeau 1909, Furon 1935, Schneegans 1943, Schöbel 1975). *Pseudotissotia nigeriensis* is also present at Damergou (Schneegans 1943), although in the Lower Turonian faunal similarity is reduced, *Thomasites*, *Eotissotia* and *Wrightoceras* being unknown there. *Pseudotissotia nigeriensis* is also present in the Algerian Sahara, as are *Nigericeras gadeni*, *Vascoceras cauvini* and forms probably conspecific with the Nigerian '*Paramammites*' of Barber (1957). The Late Cenomanian *Neolobites* faunas from the Saharan countries have no equivalent in Nigeria. Greigert (1966) showed that in west Africa they extend only as far south as southern Niger. Present evidence, therefore, indicates that vascoceratid ammonites first entered Nigeria from the north during *Metoicoceras geslinianum* Zone times. Microfossil evidence does indicate marine influence in the older Yolde Formation and, indeed, in the upper part of the Bima Sandstone (Doyle *et al*. 1982, Lawal 1982, Allix 1982) but environmental conditions seem to have been unsuitable for ammonites.

Marine microfossils are found virtually throughout the Upper Cretaceous in north-east Nigeria (Lawal 1982). Popoff *et al*. (1986) proposed that faunal exchange across the Sahara was continuous during the Late Cretaceous. The presence of *Hoplitoides* and *Coilopoceras* in north-east Nigeria indicates that marine conditions suitable for ammonites continued into the Middle and probably the Late Turonian here. Coniacian ammonites including *Forresteria* Reeside, *Barroisiceras* Grossouvre and *Tissotia* Douvillé occur in the limestones of the Sekule Formation in the Dadiya Syncline (see also Reyment 1954*a*, Barber 1960) and Santonian beds may exist a little further south (Reyment 1957). *Libycoceras* Hyatt has been found in Upper Campanian shales near Gombe (Reyment 1955, Zaborski 1982). Although, in ammonite terms, the major part of the Santonian and Campanian, and the whole Maastrichtian, are unknown, there is a growing body of evidence pointing to persistent marine conditions in north-eastern Nigeria during virtually the entire Late Cretaceous.

In southern and central Nigeria *Hoplitoides* is known in numbers from Wadatta and Igumale, while *Coilopoceras* (= *Glebosoceras* Reyment, 1954) occurs around Ogoja (Reyment 1954, 1957*a*) and north of Calabar (Zaborski 1985). *C. vandersluisi* Reyment (1957*a*: 62; pl. 10, figs 1a, b), indeed, is very similar to, and possibly synonymous with, *C. discoideum*. Kennedy & Wright (1984) suggested that *Glebosoceras globosum* Reyment (1954: 161; pl. 2, fig. 3; pl. 4, fig. 1; text-fig. 5) and *C. discoideum* may be a conspecific, dimorphic pair. Coniacian, Upper Campanian and Lower Maastrichtian ammonites are well known from southern Nigeria (Reyment 1954, 1954*a*, 1955, Zaborski 1982). Again, here it is Santonian to lower Upper Campanian forms that are unknown, although Klinger & Kennedy (1980: 110) speculated on the possibility of a Santonian age for *Reginaites quadrituberculatum* Reyment (1957*a*: 65; pl. 11, figs 1a, b) from near Agbani.

ADDITIONAL NOTE

After additional collecting at Ashaka, the following observations are relevant to the results of this paper and in particular to the position of the Cenomanian–Turonian boundary in north-eastern Nigeria. Firstly, weakly ribbed forms of *Thomasites gongilensis*, similar to those described from the Upper Cenomanian of Devon by Wright & Kennedy (1981), predominate in the Proprium Zone. Secondly, *Pseudaspidoceras* of *P. pseudonodosoides* type occurs in the Proprium Zone. And thirdly, *Pseudaspidoceras flexuosum* is present in the middle and upper parts of the Nigeriensis Zone (the species appears, however, at the base of this zone where large numbers of predominantly strongly ribbed *Thomasites gongilensis* occur). These further indications confirm the placement of the Cenomanian–Turonian boundary at or close to the top of the Proprium Zone, and the basal Turonian position of the Nigeriensis Zone.

Meister (1989) has recently published an extensive account of the Ashaka ammonites. It is not possible to make detailed comments on this work here but the following important points may be made concerning his proposed biozonation.

Meister's '*Nigericeras gadeni* Zone' corresponds not to that as proposed here, but to the Cauvini Zone. The forms he refers to *Nigericeras* are here regarded as *Vascoceras cauvini*. Such relatively compressed ammonites from this stratigraphical level at Ashaka, and elsewhere in north-eastern Nigeria, lack the typically acanthoceratid suture and seven rows of tubercles which characterize *Nigericeras*. True *Nigericeras* occurs below, in the Gadeni Zone as proposed here. This part of the sequence at Ashaka is not included in the section given by Meister (1989: fig. 41); its upper surface forms the floor of the quarry, but until 1987 it could be seen in vertical profile, but only in the eastern part of the quarry. It has subsequently been largely covered by dumping of overburden.

Meister (1989: 36) remarks on the astonishing diversity of morphotypes in the Proprium Zone and admits that he may have oversplit these faunas in his taxonomy. I think he does, and this explains the numerous biostratigraphical 'horizons' identified by Meister at the levels of the Proprium and lower Nigeriensis Zones as employed here.

Meister draws the base of his '*Pseudotissotia nigeriensis* Zone' at a higher level than that used here. The upper part of his '*Thomasites gongilensis* Subzone' is considered as part of the Nigeriensis Zone containing, as it does, the earliest, more tuberculated, forms of *P. nigeriensis*.

Meister employs *Wrightoceras wallsi* as a subzonal index with a further 'Subzone of *Fagesia superstes* or *Choffaticeras quaasi–C. pavillieri*' above. *Fagesia* of *F. superstes* type, however, extend higher than the ranges of either *W. wallsi* or *Pseudotissotia nigeriensis* at Dukul, while at Ashaka *Choffaticeras* appears not, as he suggests, at the level of his 'Superstes Zone' but considerably lower, in the middle part of the Nigeriensis Zone as proposed here.

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